ANALYSIS OF DRIVE CYCLE AND THERMAL ASPECTS OF BATTERY DESIGN FOR ENHANCEMENT OF ELECTRIC VEHICLE PERFORMANCE

SHORT SYNOPSIS

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CERTIFICATE

I hereby declare that the short synopsis "Analysis of drive cycle and thermal aspects of battery design for enhanced electric vehicle performance", being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Mechanical Engineering under faculty of engineering of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2022-23.

It is a bonafide record of original work carried out under the supervision of Dr. Devendra Vashist and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

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ABSTRACT

Drive cycle is the plot of vehicle speed with respect to time. Broadly, drive cycles can be classified as “synthesized” and “real-world” drive cycle. Synthesized drive cycles are composed of “idle”, “constant acceleration”, and “constant speed” phases. Transition from one phase to other in synthesized drive cycle fails to capture the real driving condition. To overcome this shortcoming, real world drive cycles are developed under actual traffic and road condition for different vehicles. All over the world attempts have been made to develop the real-world drive cycles. Conventionally India Drive Cycle (IDC) and modified IDC is used for vehicle emission assessment in India. IDC is a synthesized drive cycle which was developed way back 1985 and later modified. Rapidly growing economy, vehicle density on road, and road infrastructure made it imperative to study the drive cycle under actual traffic condition, to reflect the real traffic behavior of a city or geographical area in India. First aim of this work to analyze the performance and energy consumption of E-scooters on the basis of their vehicle dynamics and driving characteristics on IDC. This will serve as the reference of energy consumption on standard cycle i.e. IDC. Secondly, we aim to develop a real-world drive cycle of E-scooter for the city of Lucknow, India. This real-world drive cycle will be based on actual traffic condition, and for the peak hours timing. Thirdly, Energy consumption of E-scooter will be analyzed on developed real world cycle. This analysis will lead to the estimation of actual energy consumption by E-scooter and will be compared with IDC. Based on actual energy requirement battery sizing will be done and thermal analysis will be conducted to design effective cooling strategy of battery pack.

Key words: Battery Thermal Management, Electric Scooter, India Drive Cycle, Real World Drive Cycle, Synthesized Drive Cycle.

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1. INTRODUTION

Internal combustion engine (ICE) based vehicles are dominating the transportation sector across the world. Keeping in view of energy security and environmental concerns across the globe, ICE based vehicles are under heavy criticism **(Qiao et al., 2019)**. Electric vehicles (EVs) are emerging as the most potential alternative to conventional vehicles to reduce hydrocarbon dependence and air pollution **(Li et al., 2019)**. In Europe, to reduce CO_2 emission EV usage in Germany is projected to grow by 17 % in next five years (2022-2027) whereas UK and France have also committed to limit the in-country sales of hydrocarbon based vehicles by 2040 **(Bubeck et al., 2016)**. To encourage the manufacturers and consumers in their markets, countries are offering various subsidies and special tax provisions. UK is subsidizing plug-in EVs, whereas US provides rebate under clean vehicle rebate project. As part of their initiatives to encourage the purchase of green vehicles, Japan and China are also promoting EVs **(Palmer et al., 2018)**.

1.1 EVs in India

Government of India is also proactively taking steps forward for the transition of mode of transportation from conventional vehicles to EVs. "National Electric Mobility Mission Plan" (NEMMP) 2020 and "Faster Adoption and Manufacturing of Electric Vehicles" (FAME-II) are two of the major initiatives. With the sale of 6-7 million EVs by the end of 2020, NEMMP 2020 sought to save 2.5 million tonnes of fossil fuel **(GoI, 2013)**. Through FAME-II scheme Govt. of India is providing incentives in purchase of EVs (Department of Heavy Industry, **2019**). NITI Aayog's 2017 study envisions 100% public transit vehicles and 40% private electric vehicles by 2030 **(NITI AAYOG & The Boston Consulting Group, 2018).** Indian automobile manufacturers are aiming the sales of 40% new electric vehicles in market by 2030 **(Paper & Vehicles, 2017)**. Two wheelers segment dominates the Indian automobile sector with contribution of more than 80% in the overall sales. Among all the states Maharashtra have the highest number of two wheelers EV presence **(GIZ & Deloitte, 2021)**.

1.2 Challenges in EV adoption

There are various constraints in the adoption of EVs, such as charging time, charging infrastructure, and replacement cost of battery **(Alkhalidi et al., 2022)**. At high discharge rate battery pack get heats up which impacts performance adversely. Heating of the battery pack is also the cause of concern in Indian conditions and to address the issue, designs of cold plate, different cooling configurations such as surface ribs, pin fins and delta winglets have been studied **(Yen et al., 2017)**. But the major constrain is the range anxiety in the mind of user.

Range anxiety is the fear of "stuck" before reaching at destination due to discharge of battery **(Miri et al., 2021)**.

1.3 Drive Cycle

Drive cycle is the mapping of speed with respect to time for a vehicle driven under specific condition **(Kumar et al., 2020)**. Vehicle manufacturers, traffic engineers and environmentalists utilize the drive cycle to test and study new vehicle models for energy consumption, driving styles, environmental impacts etc. Broadly driving cycles can be classified as polygonal or modal driving cycles (DCs) and transient or real-world drive cycles. Polygonal DCs are constructed by alternating the different driving modes such as idle, acceleration, cruise and deceleration. On contrary to Polygonal DCs transient DCs are developed by using the segments of actual data from the on-road driving **(Hung et al., 2007)**. Indian Drive Cycle (IDC) falls into the category of Polygonal DCs **(Mayakuntla & Verma, 2018)**. It is evident that Asia being the most populated region, traffic is slow and congested due to which an aggressive driving behaviour is observed the same is presented in Table1.

Table 1: Comparative studies on driving cycles of Asia and Europe **(Tong & Hung, 2010)**

Region	Average Speed (km/hr)	Positive acceleration Rate	Inferences
Asia	28	high	Harsh driving behavior and congested driving condition.
Europe	42	small	Faster and smoother driving behavior.

"Automotive Research Association of India (ARAI)" worked out the "Indian driving cycle (IDC)" in the year 1985 after rigorous road tests **(Kamble et al., 2009)**. Indian drive cycle (IDC) is spanned over 108 seconds and the average speed is 21.93 km/h. Different modes in IDC have been summarized in Table 2 and described with the help of Figure 1.

Table 2:IDC Characteristics

S.No.	Particulars	Time (s)	Percentage
1	Idling	16	14.81
2	Steady speed Period	13	12.04
3	Acceleration	42	38.89
4	Deceleration	37	34.26
		108	100

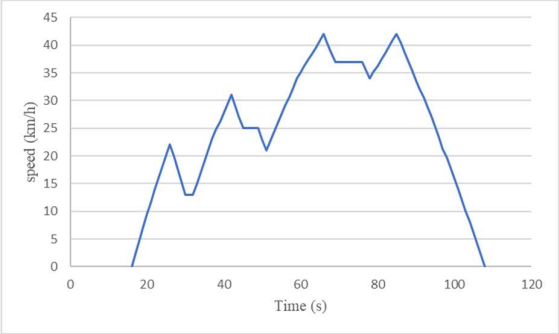

Figure 1: Indian Drive Cycle

Existing studies suggest that, energy consumption of EV estimated under official drive cycle is not capable of reflecting the energy consumption under real driving condition. To address this issue all over the world attempts are being made to develop the real-world cycle depicting the driving condition of the particular geography.

2. LITERATURE REVIEW

Electric vehicles are getting popularized in Indian market, among customers of the metro as well as tier-II cities. As the geographical and climatic condition in India is varied across the country, the performance assessment for an EV becomes very crucial for a particular geography. This literature review is focused under two aspects:

- Performance assessment
- Performance Improvement

Performance assessment aspect is addressed through the development of drive cycle to depict the actual traffic conditions in Indian cities. Drive cycles are used for the assessment of energy consumption. However, battery thermal management (BTM) aspect is explored to improve the battery performance in the summers of central north India.

2.1. Development of Real-World Drive Cycle

Drive cycles are broadly categorized as transient drive cycle and 'modal' or polygonal drive cycle. Transient drive cycle is developed from the data acquired through on road driving. However modal drive cycle is composed of series of steady state modes **(Tong & Hung, 2010)**.

An intra-city bus drive cycle for Chennai has been built by taking into account 6 routes, travel distances of 12–26 km, road widths of 7–24 m, traffic light counts of 14–36, trip durations of 70–120 min, and bus stops of 16–24. On-board data collection method was used and GPS was installed on the vehicle to acquire second by second speed vs time data. Data collection took place between 5:00 to 7:30 p.m. during the evening peak period and between 7:30 to 9:30 a.m. during the morning peak period. To construct the drive cycle fourteen drive parameters have been identified, and micro-trip-based approach was applied **(Nesamani & Subramanian, 2011)**.

An E-Rickshaw drive cycle is developed for the selected route of length 14 km in Sangareddy district in the state of Telangana, India. During the months of November and December 2019, data from 100 trips during the morning and evening rush hours were gathered using a GPS logger fitted on the test vehicle (a Mahindra e-Alpha). Micro-trips were produced following data collecting. Drive cycle construction was approached through two different methods, random selection method and K-mean clustering techniques. It was found that the drive cycle constructed using K-mean clustering has less relative and mean relative errors compared to random selection method **(Chandrashekar et al., 2021)**.

In Fujian, China, researchers applied Simulated Annealing (SA) on second-by-second driving data to develop a transient drive cycle for light duty vehicle. This method demonstrated

a 16.5%-23% reduction in error compared to conventional micro-trip, clustering, and Markov Chain methods. Researchers has proposed for the further work with SA method to explore for electric vehicles and other class of vehicle as well as other geographical regions **(Cui et al., 2021)**.

Xuan Zhao and team attempted to develop an electric vehicle (EV) drive cycle for Xi'an city of China. An all-electric BYD E6 served as the test vehicle, and information was gathered using a hybrid mode through "chase car method and on-board instruments". To process the original data firstly wavelet decomposition was applied to address the issue of data distortion and disruption. A "fuzzy C-means (FCM)" clustering technique was applied for classifying the driving segments, and "Principal Component Analysis (PCA)" is used to lessen the kinematic parameters. Comparison of developed drive cycle and standard international cycles revealed that international cycles were estimating 9.65 to 21.17% error in energy consumption, however in case of driving range estimation error was 20.10% **(Zhao. X et al., 2019)** .

Supercapacitor electric bus drive cycles are also now available for usage in the city of Hong Kong. The chosen path was 4.5 kilometres long and took about 26 minutes to complete. On board data collection was done using the GPS device with in iPhone 6S, with the installed application "MyTracks". Micro-trips were formed out of collected data and randomly chosen to form the candidate cycle. 13 kinematic parameters were used to asses the candidate cycle against the target cycle **(Tong, 2019)**.

To construct a hybrid electric bus (HEB) drive cycle for the city of Shanghai, China, driving data was collected using on bord recorder. Under this study firstly a HEB drive cycle of 1200s has been constructed with conventional method, as 12 driving kinematic parameters were chosen, and applying the k-mean clustering method. The bus stop and start frequently, so use of micro-trip-based method to develop drive cycle becomes computationally cumbersome. To address the issue kinematic segments with fixed time-steps has been used as improved method of HEB drive cycle development **(Shen et al., 2018)**.

Using an on-board data recorder, actual driving data and engine parameters were gathered to build the urban drive cycle for Malaysia. From recorded data, micro-trips were generated, and further k-mean clustering is done for the for segregation of micro-trips. Means of each cluster formed are used as target criteria to select the micro-trips, to construct the candidate drive cycle. Comparison of developed cycle with NEDC reviled that Malaysian urban drive cycle shows only 8.5% of deviation from actual fuel consumption, against of 43.1% with NEDC **(Abas et al., 2018)**.

Yuhui Peng and team attempted an approach of developing the car drive cycle for Fuzhou city, China, by generating micro-trips, clustering by k-mean method and application of Markov chain. Actual driving data was collected using on board recorder for 20 weeks (working days and weekends also), during rush hours as well as off peak hours. A MATLAB code was developed to divide the entire 2398275 s of speed-time data collected into micro-trips. 11619 micro-trips were formed and 15 kinematic characteristics were computed for each micro-trip. Using SPSS, principal component analysis is performed on 15 parameters, and it was found that the contribution rate of first 3 eigenvalue is 87.45%. Final drive cycle was constructed for the time duration of 1200 s **(Peng et al., 2020)**.

Jin Zhang and team implemented an improved Micro-trip method with less computation and better accuracy, to form the drive cycle for electric taxi in Beijing. They proposed an improve Markov Monte Carlo method which considers the road environment in drive cycle **(J. Zhang et al., 2019)**.

Ruoyun Ma and team developed a passenger drive cycle for Beijing, the capital city of China. Route was composed of expressway, arterial road and residential road. Data was collected from 459 private passenger cars on second-to-second basis. Data collected were formed into micro-trips and by applying k-mean clustering, seven clusters were formed. Each cluster indicate single state and Markov chain is formed by state space which is a combination of all states. Developed drive cycle comparison with NEDC shows that for Off-peak and Peak cycle the energy consumption is higher by 30% and 38% respectively. This indicates the requirement of real world drive cycle for the particular area **(Ma. R et al., 2019)**.

To construct the real-world drive cycle in Fuzhou city of China, on board data collection was done. Abnormal and distorted data is processed first and data smoothing is done using time-series smoothing algorithm. For data interpolation Lagrange's interpolation is used. K-mean clustering is applied to segregate the micro-trips in clusters. Further adaptive particle swarm optimization helps to determine the ideal micro-trip segments for the drive cycle **(Zhao. M et al., 2021)**.

Drive cycle for Kuala Terengganu city of Malaysia have been developed by collecting on board data using GPS. Five routes were chosen for data collection and collected data were converted into micro-trips. Kinematic features like average speed as well as percentage of idle have been calculated for each micro-trip. After application of k-mean clustering, candidate cycle was formed. Further, Energy consumption of different power train (eg. IC engine, series PHEV, parallel PHEV) have been compared on the developed drive cycle **(Anida & Salisa, 2019)**.

In India, Pune drive cycle was developed using chase car method. From collected data micro-trips were generated. Data analysis is carried out by analysing base data as well as micro-trips. From collected and pre-processed data, speed and acceleration frequency matrix MF_b as well as normalized speed and acceleration matrix MN_b are generated. Target parameters are calculated by using these matrixes. Similar analysis is done for the micro-trips also and travel characteristics are determined. Duration of Pune drive cycle achieved is 1533 s. In comparison with IDC and European drive cycle, it was found that Pune drive cycle have higher speed and sharp acceleration -deceleration **(Kamble et al., 2009)**.

The use of "microtrip" as the fundamental building block for creating driving cycles has several drawbacks, and a new one termed "trip segment" is introduced in the study conducted for the development of drive cycle for Bangaluru city. Both, an algorithm for extracting those segments from raw data and an algorithm for creating a representative cycle using those travel segments are described. The methodology is suggested with the intention of capturing the variation within micro-trips, which is particularly important for vehicles moving in a highly varying traffic condition, like cities in India **(Mayakuntla & Verma, 2018).**

Based on actual driving data of EVs in Beijing, EV cycle is produced using statistics and the methodology of Markov chain. The evaluation's findings demonstrate how well the designed driving cycle captures the real-world data. In cities like Beijing, the developed drive cycle can help in the evaluation and life cycle analysis of EVs **(Gong et al., 2018)**.

Hong Kong traffic issues prompted the development of three driving cycles (i.e., urban, sub-urban and highway). These cycles' evaluation parameters differ significantly from worldwide driving cycles like FTP and ECE, indicating Hong Kong's unique driving conditions **(Hung et al., 2007)**.

Actual drive cycle for shared 3 Wheelers in Dhanbad, India differs from IDC used for legislation, especially in terms of “idle time”, “average speed”, “average acceleration”, as well as “deceleration”. Due to their structure, gross weight, and purpose, shared auto-rickshaws and motorcyclists have different driving patterns. Using the same driving cycle to determine CO, HC, and NOx emissions for both vehicle classes shows substantial differences. Real-world DC for passenger vehicles differs substantially from MIDC in the driving mode duration such as, “average speed”, “maximum speed”, “average acceleration” and deceleration, and emission estimates. For more realistic emission estimates, consideration of region's actual driving cycle is vital **(Adak et al., 2016)**.

As results of a Hamburg (Germany) bus measurement campaign, the data obtained spans more than a year and 315,583 kilometres with 27,365 h of operation from outskirts to

city core. Statistically assessed data is presented. A parameter set and their distribution are utilised to describe an upgraded micro trip model. The results show that the generator output matches actual traffic behaviour better than the reference driving cycles **(Günther et al., 2017)**.

GPS gathered speed data second-by-second. Morning peak (7:00 to 9:00 a.m.), afternoon peak (4:00 to 6:00 p.m.), and off-peak (2:00 to 3:00 p.m.) speed-time data was gathered in two weeks, excluding weekends. 10 parameters were used to evaluate driving cycle errors. Acceptable error was 5%. Lower error means a more realistic driving cycle. If the mistake is higher than 5%, the driving cycle is redeveloped using micro-trips. This is done until the error becomes lower than 5% **(Pouresmaeili et al., 2018)**.

Real driving data from Chennai, India, is used to design a driving cycle for cars and motorcycles. Peak and off-peak passenger car driving behaviour differed significantly, hence distinct driving cycles were developed. Speed and acceleration frequency distribution charts were utilised to understand operating modes. The designed driving cycle was compared to current cycles to emphasise Chennai's traffic issues **(Arun et al., 2017)**.

This work provides a drive cycle created by gathering data from several places of India and testing it over 2500 km in towns, roads, and ghats. Micro-trips are generated from road trial data. Drive cycle and actual world data were compared using nine kinematic parameters. **(Sriniwas et al., 2011)**.

Lack of representative driving cycles for the cities of Egypt and the widespread use of established cycles for developed countries prompted the development of first drive cycle. Microtrips were utilised to generate driving cycles using K-means as well as K-medoids clustering. Both algorithms' drive cycles were similar. The K-medoids algorithm driving cycle averaged 16.3% idling time, 12.5 km/h, and 0.215 m/s2 acceleration. The designed cycle was evaluated against ECE and FTP-75. In terms of drive cycle parameters, predicted “fuel consumption”, and “emission rates”, the developed cycle was more indicative of the actual data than the legislative cycles **(Huzayyin et al., 2021)**.

Time series clustering and using second-by-second driving data from a 1,100-second, 11,481-kilometer trip, a representative bus driving cycle was built. The desired route was west-north Thailand's Route 323 in Kanchanaburi. 51.8% of speeds were 30-40 km/h. The best solution for trip interval time was 40 seconds with average speed, which is similar to actual driving data. Results showed that a driving cycle data set had low mean absolute error and deviation change values. Considering the time spent in each mode, the percentage difference between acceleration and deceleration modes varied by 9.19%. This meets the criteria by 10% **(Mongkonlerdmanee & Koetniyom, 2019)**.

Jinan's driving cycle is built using the k-MPSO clustering technique. Three classifications are created from the obtained data using “PCA” and the “k-MPSO” clustering technique to represent the driving characteristics of Jinan. The suggested approach is a practical and effective way to apply the k-MPSO clustering algorithm to conventional driving cycle construction **(Yan et al., 2020)** .

Xi'an's driving pattern for electric automobiles is developed and methodology include selection of routes, data gathering, data processing, and driving cycle construction. Data is collected employing a chase car as well as on-board measurements. Principal component analysis reduces motion characteristic parameter dimensions, and K-means as well as support vector machine hybrid identify driving segments. “Markov and Monte Carlo” simulations are used to build the real driving cycle. “Relative error”, “performance evaluation”, and “speed-acceleration probability distribution” are utilised to choose the most representative driving cycle **(Zhao. X et al., 2020)**.

Ludhiana city in India, driving cycles were devised to assess car emissions, but not speed or acceleration. In India, vehicle activity is diverse. The driving cycle was developed using real-world micro-trips. Clustering micro-trips with K-means. The drive cycle is developed using realistic micro-trips. Route- and mode-wise driving cycles were designed. The new cycle was analysed and compared to Delhi's condition. **(Yugendar et al., 2020)**.

2.2. Battery Thermal Management (BTM)

A system to address the issue of battery’s thermal aspect, aims to maintain a pack of battery at optimal aggregate temperature with uniform temperature across system **(Pesaran, 2001)**.

EVs powered by Li-ion batteries have not been generally adopted by customers despite its allure. The battery system's primary drawbacks include its high capital cost, short life span, concerns of safety , as well as thermally-induced deterioration **(Conte, 2006)**.

Enough research has not been done on the advancement of battery thermal control systems, despite their impact on battery behaviour, expected life span, and safety. Li-ion batteries can operate between 20 and 60 °C, however they function best between 15 and 35 °C, also the difference in temperature between the cells and battery modules the pack should be less than 5 °C at most **(Väyrynen & Salminen, 2012)**.

When designing electric vehicles, safety should be the most important thing. So these vehicles need a good BTMS to quickly get rid of the heat that builds up within battery pack. In case of lower temperatures, preheating is performed for EV batteries **(Liu. H et al., 2017**).

Many EVs have utilised air as cooling medium because of the requirement of simpler design, as result of that maintenance as well as production cost goes down**(Chen. K et al., 2017)**. Due to air's poor thermal properties, this method becomes less appropriate in managing a uniform temperature within and among the cells of battery pack. Consequently, it is more challenging to drain out large amount of battery heat in comparison to a comparable liquid flow rate. In recent years, the cooling air system of casing of for Li-ion batteries has been improved primarily in three areas: the shape of the air channels, how the cells are set up, and how air flows through them **(Kim & Pesaran, 2006)**.

Slant manifold and pressure relief ventilation can accomplish the desired cooling performance without modifying the battery system's layout/design **(Park, 2013).** Design of Experiment method and a 3-D heat transfer model were used to create an ideal "Z-type" flow battery pack. Simulations demonstrate that both input and output flow duct layouts impact cooling stream flow rates, which may alter aggregated cell temperature in a "Z-type" circulation pack, aggregated cell temperature variation throughout the pack, and total pressure loss. **(Sun & Dixon, 2014)**.

Four distinct layouts of longitudinal ribs are studied for cooling channels to improve heat transfer and cooling efficiency. Also, rib channels are compared with non-rib flow networks for parameter effects. The optimised ribbed structure boosts heat transfer by 68%, shrinks down the flow of mass by 16%, and reduces power to pump by 20% **(Ashkboos et al., 2021)**.

For thermal control of Li-ion battery packs, a particular pin fin heat sink with increasing fin heights in the flow direction was developed. 3-D transient study (thermal) of an air-cooling based module with prismatic Li-ion cells projected with pin fin for heat rejection was researched to determine the impacts of pin fin configurations on battery performance. Heat exchangers with consistent elevations of pin fins increases the temperature field's standard deviation **(Mohammadian & Zhang, 2015)**.

Aluminum metal foam enhances Li-ion battery cell thermal control compared to no porous insert. Increasing the metal foam's permeability improves temperature non-uniformity and lowers battery temperature. It demonstrates that a sparse matrix is preferred over a dense one if the major objective is to reduce the over all temperature for enhancing the safety **(Mohammadian et al., 2015**).

It is suggested to use bidirectional air flow cooling systems to improve cooling effect. Results show that jet cooling can reduce heat accumulation in intermediate cells. Passage of air at the bottom conduit will improve heat transfer between the bottom plate and batteries.

Two air channels boost fan efficiency. The suggested approach might give a relatively low temperature and more consistent range of temperatures while maintaining same pack of battery **(Yu et al., 2014)**.

To maximise battery module thermal performance, different cell arrangement patterns are examined. 1x24, 3x8, 5x5 arrays rectangular, 19-cell hexagonal, and 28-cell circular. Installing fans at different battery module locations is also studied. Forced air cooling reduces battery module temperature. Length and cross-sectional area of airflow path, air temperature, and airflow speed affect cooling ability. In the considered case, fan placement on top of the battery module improves cooling irrespective the pattern of cell placement **(Wang et al., 2014)**.

Using a commercial CFD code, thermal evaluations of module having prismatic Li-ion cells cooled by air medium is studied. The existing module cooled each cell with air through evenly-spaced tubes. Lower gap distance and greater fan speed reduced maximum temperature rise. Moderate gap spacing improves module temperature consistency. Given the module design, running with a consistent gap of 3 mm and flow rate of air 40.8 m^3/ h seems to satisfy temperature requirement. Dual-side cooling is more effective than single side cooling with the same spacing and flow parameters of air. Inconsistent separation distance influences temperature but temperature rise remain unaffected **(Fan et al., 2013)**.

An arrangement of 8 single cell battery pack paired axially is used to simulate the influences of radial distance and flow velocity on air cooling performance. Increasing the battery pack's radial separation causes a minor rise in average temperature (approximately 0.56 C^0 at single air flux) but improves thermal homogeneity. Increasing the radial separation 2 to 10 mm reduces power costs by the amount of 95.7% **(Yang et al., 2016)**.

Secondary loop liquid cooling can manage the correct battery temperature in a relatively small design of battery pack under severe environmental parameters, like drawing or pumping the power in at elevated temperature of air **(Krüger et al., 2012)**.

Cells can be coupled to high-conductivity fins and a heat exchanger **(Sarazyn, 2014).** A cooling system may include both passive as well as active cooling components. In the active portion, flow of air is utilized inside the cooling channels, while graphite related composites served as the PCM in the passive portion **(Fathabadi, 2014)**. According to studies, practically all PCMs have thermal conduction properties at lower side, allowing heat to accumulate under demanding operating circumstances. Adding high-carbon compounds increases thermal conductivity **(Chen. J et al., 2019)**.

PCM is a substance that, through a process, either collects or emits heat. At a particular temperature, of transitioning from one phase to another. These have been extensively utilised

in a variety of fields, including civil and energy engineering because it has a high heat capacity and can release heat by methods of phase transition without the use of energy **(Elefsiniotis et al., 2014)**. As the temperature goes up steadily, PCM gradually take up heat in the form of sensible heat initially, followed by a significant as latent heat during the change of phase process is complete and it reaches the melting point. This indicates that it can withstand the battery's extreme thermal load without experiencing unusual temperature rises or substantial temperature irregularity **(Wilke et al., 2017)**.

Since batteries are becoming powerful in recent years, BTMS requires heavy cooling. But this kind of system isn't ideal because it makes the system more complicated and makes the compressor use more power. The PCM cooling system is one way to make up for these flaws **(Sharma et al., 2009)**.

Using phase-change heat transfer, a heat pipe is a device that can run on its own without the need for externally supplied power and move enormous amounts of heat energy over long distances at rapid rates. This is true even for temperature differences as small as 0.1 degrees Celsius. It also offers characteristics such a compact structure, flexible geometry, a long lifespan, and little maintenance, making it useful for efficient heat control in a variety of sectors **(Huber, 2017)**.

The possibility of using thermoelectric elements as environment friendly energy management has attracted a lot of attention to research and advancement in the last ten years **(Liu. Y et al., 2014)**. Cold side of the Peltier plate is attached to the battery, while the high temperature end is connected towards the cooling plate through which coolant flows. By altering the direction and amount of DC, thermal behaviour of TEG can be controlled **(Zhang. C et al., 2020)**.

A trend has been seen that across the world researchers are developing drive cycles depicting the actual traffic conditions of a particular city, especially for EVs. It is the requirement of the moment, because the legislative cycles fail to estimate the actual energy consumption by EV. For Indian cities very less work has been done in this direction even though governments are giving thrust for EVs adoption. Analysis of battery thermal management is crucial in Indian conditions, because it is very usual for surrounding temperature to go beyond 45 C^0in summers. Li-ion batteries of EV's catching fire, became the headlines in summers and were the setback for the EV market. There is a need to explore the thermal aspect of the battery pack for safe and optimum performance of the same.

3. DESCRIPTION OF BROAD AREA

Drive Cycle:

Drive cycle is the speed vs time data acquired for a vehicle under different traffic conditions. Drive cycle depends on the types of vehicles, road condition, driver, traffic flow and other environmental factors.

Cycle construction methods comprises of the steps given below:

i. Real-world drive data collection,
ii. Segmenting driving-related data,
iii. Developing cycles,
iv. Cycle evaluation and selection.

3.1. Collection of Real-World Driving Data

i. **Route Selection**

Route selection is essential to generate driving cycles. Non - representative routes result into failure of capturing real traffic behaviour and drive cycle developed deviates from actual scenario. Routes should reflect the actual network and usual traffic conditions, land usage, road type, topography, traffic signal, and the population density of the location.

ii. **Collection of Data**

Chasing car method and on-board measuring method are two data collection methods. Hybrid data collection combines these two strategies.

- **Car Chasing Method**

Car chasing method is a prominent approach of collecting data for the construction of driving cycle. In this strategy, a vehicle installed with instruments is utilised to chase a predefined vehicle in a predetermined area. Drivers must follow the target vehicle to collect reliable data, which is problematic on roads with low level of service (LOS). One of the best things about the chasing car method is that it uses less resources than other methods. Because of this, it is much cheaper than using the on-board method of data collection. Major shortcoming is the difficulty to follow a vehicle when drivers are driving aggressively, which might lead to accidents.

- **On Board Data Collection Method**

In on-board data acquisition, instruments are put in selected vehicles and driven along selected routes. As they travel, speed data is captured for each second.

3.2. Construction of Drive Cycle

Purpose determines cycle construction method: pollution inventories, fuel consumption, or transportation engineering. Each approach of cycle construction has unique traits that reflect its aim. Micro-trip, segment, pattern categorization, and Modal cycle creation are four basic methodologies.

i. Micro-Trip Method of Cycle Construction

Movement between adjacent stops, including an idle interval in forward, is a micro-trip. Data collected is divided into micro trips and segregated based on average speeds. Construction of is done applying micro-trips consequently population parameters are achieved. Random selection and best incremental technique are used to choose micro-trips for the cycle. Some driving cycles combine the two techniques. Stop-and-go driving caused by traffic lights and congestion increases fuel consumption. Micro-trip method is superior for emissions and fuel estimation.

ii. Segment-Based Method of Cycle Construction

Similar to “micro trip-based” drive cycle design, “segment-based” method of cycle formation considers the route type or LOS while picking a travel "segment" instead of neighboring stops. Since this system divides the journey into pieces based on traffic conditions and the physical characteristics of the route, it can begin and terminate at any pace. Linking trip divisions into a driving cycle requires matching speed as well as acceleration between micro-trip connecting points (seconds of time). This strategy is best suited for the driving cycle catering to traffic related engineering objectives.

It was determined that segment-based cycle building is more suitable for establishing a drive cycle for expressways. Since, no nearby stops between the starting and end on an expressway, it is difficult to employ the Micro trip related method. So, the segment-based strategy can be utilized in places or on roads where fewer stop-and-go situations or if the durations of the subsequent stops are likely to be lengthy.

iii. Cycle Construction with Pattern Classification

The entire travel data is separated into heterogeneous groups using a statistical technique, and "kinematic sequence" is considered while dividing the trip. Succession probability is used to estimate the possibility of an occurrence that may occur after a particular activity. Cycles are created by randomly selecting “kinematic sequences” over the divided activity classes, taking probability and chronology into account.

iv. Modal Cycle Construction

Actual driving characteristics are split into acceleration, deceleration, cruising, and idling components during modal cycle development. To make a driving cycle, Markov Chain theory is applied under the assumption that probability of specific modal event depends only on the probability of the preceding modal event. Modal method of cycle construction has following four steps:

a. The gathered data is separated into fragments on the basis of acceleration using the Maximum Likelihood clustering technique.
b. Using Maximum Likelihood clustering method, briefs are a put to the specific buckets based on average, minimum, as well as maximum values of speeds as well as acceleration.
c. Define modes based on rate of acceleration and aggregate speed, to generate a "transition matrix" including the probability of mode transitions.
d. Using a Markov chain and a transition probability matrix, snippets are chained into a single cycle.

3.3. Cycle Assessment

Many nations have utilized Performance Value (PV) to evaluate the respective cycles. For the computation of PV, it is important to find population target parameters and candidate driving cycle target parameters. The percentage difference between the target and candidate cycle parameters are computed.

"Speed Acceleration Probability Distribution" (SAPD) or "Speed Acceleration Frequency Distribution" (SAFD) is a prevalent method for evaluating expected driving cycles. In the evaluation, acceleration versus speeds against probability are represented in three-dimensional graph.

Battery Thermal Management System (BTMS) for Li-ion Battery Pack

Nearly all cell materials lose performance and stability at anomalous temperatures. Environmental factors and chemical interactions while charging and discharging cause batteries to heat up. Therefore, a "battery thermal management system" (BTMS) is the vital aspect for obtaining the optimum temperature conditions. Temperature between the range of 15 °C to 35 °C is suitable to avoid the damaging of Li-ion batteries.

Different classifications exist for battery cooling systems. First, battery cooling systems are categorized by medium: air, liquid, and Phase change material (PCM). Another factor is power usage, where active cooling uses an energy source in addition to the ambient environment whereas passive cooling solely uses the ambient environment.

Thermal cycle can also be the basis for the classification of BTMS. It's classified into BTMS with and without the vapour compression cycle (VCC). The classification is presented in Figure 2.

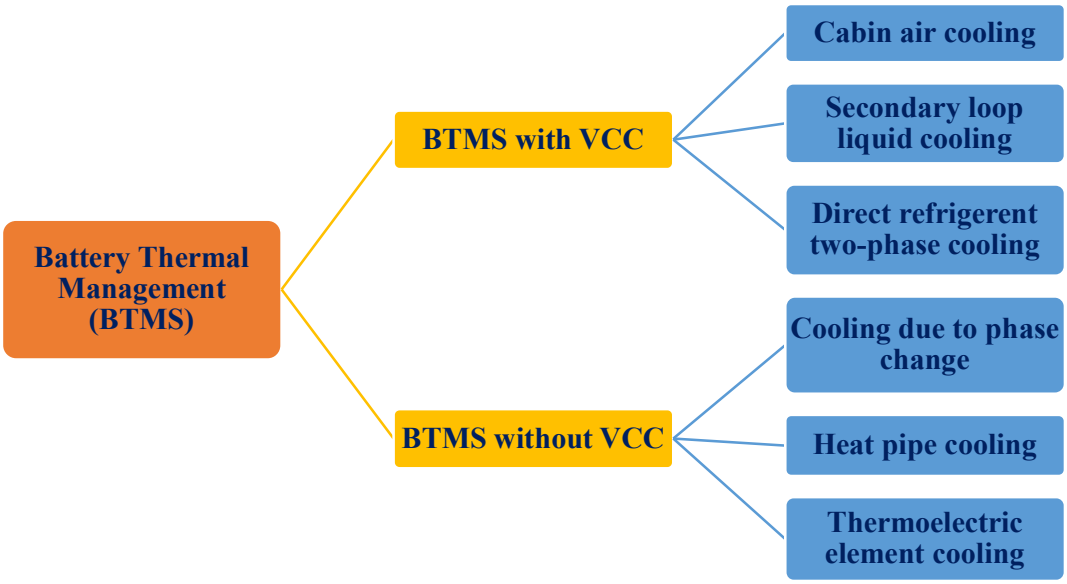

Figure 2: Classification of BTMS based on thermodynamic cycle

Electric two wheelers in India are mostly cooled passively, but keeping in view of shoot of temperature during summer season an effective cooling system is required to devised.

4. RESEARCH GAP FROM LITERATURE REVIEW

Transition from Internal Combustion Engine operated vehicles to Electric Motor operated vehicles is a technological revolution. It not only requires self-public adoption, but also an industrial regime change.

The following are the shortcomings found in the literature review:

- Adoption of electric vehicles (EV) as preferred transportation medium, is facing a challenge in the form of "range anxiety" to the drivers. Right estimation of energy requirement becomes mandatory to evaluate the vehicle range correctly. Generally standard drive cycles in practice to determine the energy requirement. In various studies it has been concluded that, these standard cycles estimate very less than the consumption of energy in actual driving condition. So, it is the requirement to develop real traffic condition depicting drive cycle for a given region and vehicle type.
- It has been found that many a times the drive cycles developed for Internal Combustion Engines (ICE) are being utilized for evaluating the range as well as energy related requirements of EVs. As EVs torque, power and braking characteristics are different than IC engines, there is a requirement to develop the real-world drive cycle for EVs.
- There are very few real-world drive cycles have been developed for Indian cities. Among the developed real-world cycle for Indian cities, very few are for EVs. So there remains a need to develop region wise real world drive cycle.
- Most of the actual traffic drive cycles developed for EVs in Indian cities are for electric buses, and electric rickshaw. Keeping in view of India as emerging manufacturing and market for electric two wheelers, it is a need for the real-world drive cycle specific to electric two wheelers.
- On the basis of actual drive condition data and prevailing high temperature range in summers of India, there is a need to analyse the heat generation and thermal management for the battery pack. This analysis is required for safe and optimum operation of battery pack.

5. OBJECTIVES OF THE STUDY

The work described in this research plan includes an exploration of the fundamentals of EV components performance. Following tentative objectives are identified to accomplish the stated work:

1. To analyse and compare the energy consumption of Electric two-wheelers based on vehicle dynamics and driving characteristics on India Drive Cycle (IDC).
2. To develop a real-world drive cycle of electric two-wheeler for a selected city of India.
3. To analyse energy requirement of Electric scooter based on the driving characteristics of developed real world drive cycle and compare with IDC.
4. To conduct the thermal analysis of battery pack for electric two-wheeler for Indian summer condition.

6. PROPOSED RESEARCH METHODOLOGY

This work employs GPS data of each second, gathered from an electric two-wheeler in order to construct driving cycles for variable traffic circumstances. The process of constructing driving cycles constitutes the “clustering” of micro-trips using the “k-means” clustering technique and sequencing clusters using the one-step Markov modelling procedure. The constructed drive cycle will be compared to those that already exist.

From the second-by-second speed data, micro-trips will be constructed with the assumption that a micro-trip begins when speed increases from zero and ends when speed decreases to zero. Thus, every micro-trip terminates with a period of idling.

k-means clustering is then used to classify micro-trips into several groups. Using the elbow plot, the appropriate number of clusters will be determined. Kinematic assessment parameters are used to determine how accurately the candidate cycle represents the entire dataset.

After the construction of drive cycle, it will be compared with IDC for the estimation of energy requirement for the EV. Further thermal analysis of battery pack will be done, considering the summer condition prevailing outside. The complete process is explained with the help of flow chart show in Figure 3.

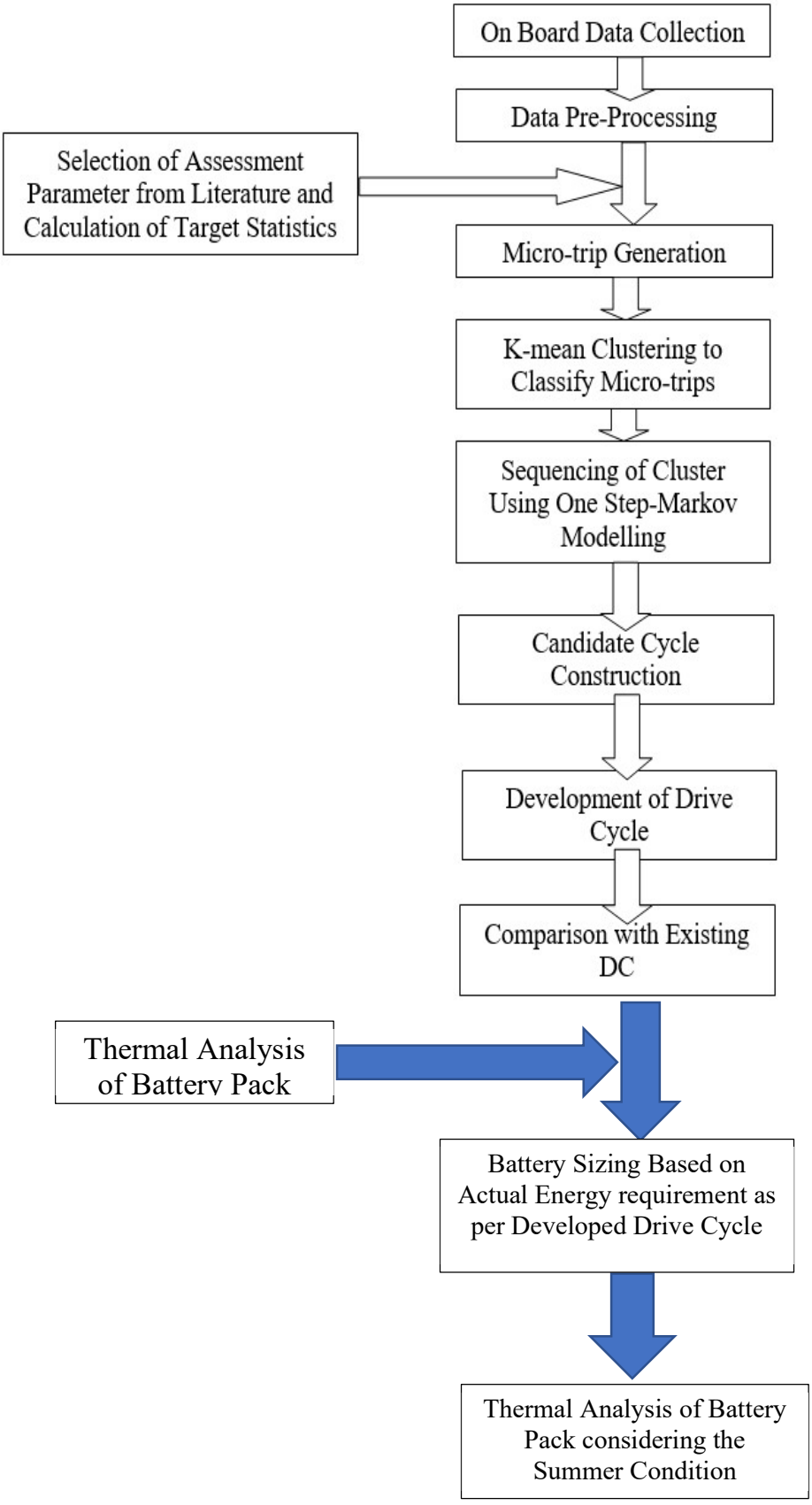
On Board Data Collection
Data Pre-Processing
Selection of Assessment Parameter from Literature and Calculation of Target Statistics
Micro-trip Generation
K-mean Clustering to Classify Micro-trips
Sequencing of Cluster Using One Step-Markov Modelling
Candidate Cycle Construction
Development of Drive Cycle
Comparison with Existing DC
Thermal Analysis of Battery Pack
Battery Sizing Based on Actual Energy requirement as per Developed Drive Cycle
Thermal Analysis of Battery Pack considering the Summer Condition

Figure 3 : Proposed work flow diagram

7. EXPECTED OUTCOME OF THE RESEARCH

The proposed research will analyze the aspects that influences the performance of EVs. The parameter on which the focus will be made are drive cycle and heat dissipation from battery. The present research will help in

- Performance analysis and energy consumption of E-scooter on standard drive cycle i.e. IDC.
- Development of actual drive cycle of EV for selected local condition in India.
- Comparative analysis of energy consumption and battery sizing of EV on the basis of real-world drive cycle and IDC.
- Thermal analysis of battery pack for high temperature condition in the summers of India.

Findings of the study will be shared with OEMs for improved product design. Results of analysis of EVs with modified battery cooling data will be shared with battery and EV manufactures for incorporation of the suggested changes.

8. PROPOSED WORK PLAN SCHEDULE

Timeline for the major activities planned are provided in Figure 4.

S. No.	Time Line	2022			2023												2024					
	Activity	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
1	Short Synopsis/Fixation of Topic																					
2	Review of Literature																					
3	Data Collection																					
4	Drive cycle development																					
5	Comparative analysis and Battery Sizing																					
6	Thermal Analysis of Battery Pack																					
7	Eligibility Approval																					
8	Long Synopsis																					
9	Pre-PhD Presentation																					
10	Thesis Submission																					

Figure 4: Timelines

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ANALYSIS OF DRIVE CYCLE AND THERMAL ASPECTS OF BATTERY DESIGN FOR ENHANCED ELECTRIC VEHICLE PERFORMANCE

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by Bhaskar Pandey

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ANALYSIS OF DRIVE CYCLE AND THERMAL ASPECTS OF BATTERY DESIGN FOR ENHANCED ELECTRIC VEHICLE PERFORMANCE.

SHORT SYNOPSIS

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ABSTRACT

Drive cycle is the plot of vehicle speed with respect to time. Broadly, drive cycles can be classified as "synthesized" and "real-world" drive cycle. Synthesized drive cycles are composed of "idle", "constant acceleration", and "constant speed" phases. Transition from one phase to other in synthesized drive cycle fails to capture the real driving condition. To overcome this shortcoming, real world drive cycles are developed under actual traffic and road condition for different vehicles. All over the world attempts have been made to develop the real-world drive cycles. Conventionally India Drive Cycle (IDC) and modified IDC is used for vehicle emission assessment in India. IDC is a synthesized drive cycle which was developed way back 1985 and later modified. Rapidly growing economy, vehicle density on road, and road infrastructure made it imperative to study the drive cycle under actual traffic condition, to reflect the real traffic behavior of a city or geographical area in India. First aim

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